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Multicast Routing Based on the Simulated Annealing*

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Abstract: Based on the simulated annealing, we propose an efficient algorithm for generating a low-cost multicast routing with delay constraints. The algorithm starts with a backup-paths-set from the source node to each destination node by using the Dijkstra shortest path algorithm, and then generates the corresponding neighborhood structure. When temperature decreasing, a new solution is selected from the neighborhood structures according to the acceptance probability and replace the old solution. The simulation shows that our algorithm is efficient for some actual networks.

Keywords: multicast routing; simulated annealing; delay constraint

Classification: AMS(2000) 68M10 **CLC number:** TP393 **Document code:** A

1 Introduction

As computer networks become faster, new multimedia services such as videoconferencing are being offered. As a typical multimedia application, videoconferencing requires the multicast routing algorithm[1]. A good survey for multicast routing algorithms is provided by Salama[2]. Multicast routing algorithms can be classified into two categories. The first category is the shortest path algorithms, which minimize the cost of each path from the source node to a multicast group member node. The other category is the minimum Steiner tree algorithm whose objective is to minimize the total cost of the multicast tree. The first heuristic for delay constrained minimum Steiner tree problem was given by Kompella[3] and is referred to KPP. The heuristic is dominated by computation of a constrained closure graph which takes time $O(u|v|^3)$. When the link delays and u takes non-integers, KPP is guaranteed to construct a constrained tree if it exists. The bounded shortest multicast algorithm, BSMA, is another delay constrained minimum Steiner tree algorithm that is constrained the best in terms of tree cost[4]. BSMA iteratively replaces the edges in the tree until the tree cost cannot be further reduced. The time complexity for BSMA is $O(k|v|^3 \lg|v|)$, where k may be very large in the case of large, densely connected networks, and makes it difficult to achieve acceptable running time.

We use one of the well known artificial intelligence techniques, simulated annealing (SA), for solving this problem, which has been successful on similar difficult combinatorial problems[5-7]. Basically, the algorithm starts from an initial feasible topology and continues its search around the neighbor topologies until a certain stopping criterion is satisfied. Its stochastic properties

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could prevent it from getting stuck to local minimum unlike the traditional greedy local search techniques. In this paper, we propose an efficient algorithm based on SA for generating a low-cost multicast tree subject to delay constraints. We call this algorithm simulated annealing for delay-constrained low-cost multicast routing algorithm (SADLMA). The algorithm starts with a backup-paths-set from the source node to each destination node using the Dijkstra Kth shortest path algorithm, and then generates the corresponding neighborhood structure. When temperature decreasing, a new solution is selected from the neighborhood structures according to the acceptance probability and replace the old solution. The simulation shows that our algorithm is efficient for some actual networks.

2 Problem formulation

Mathematically, the delay-constrained low-cost multicast routing problem can be formulated as follows. Given a graph $G = (V, E)$ with node set V and edge set E, we define two objective functions, $c(u, v)$ and $d(u, v)$, on each edge $(u, v) \in E$. Let $c(u, v)$ be the cost of edge (u, v) and $d(u, v)$ be its delay. We assume that $c(u, v) = c(v, u)$ and $d(u, v) = d(v, u)$. Let $P(u, v)$ be a constrained shortest path from u to v, where a constrained shortest path between nodes u and v is defined as the path with the least cost from u to v subject to the constraint that the total delay along this path from u to v is less than the delay constraint $\triangle$. Let $C(u, v)$ and $D(u, v)$ be the cost and delay of this path, respectively. Let $|V| = n$, $|E| = m$. On this graph, we have a source node s, and a set of destination nodes M called the multicast group. The vertices from the set $V - M - s$ are called Steiner vertices. We try to construct such a Delay Constrained Steiner tree T rooted at s that spans the destination nodes in M so that for each node m in M, the delay on the path from s to m is bounded by a delay constraint $\triangle$.

For each $m \in M$, if $p(s, m)$ is the path in T from s to m, then

$$\sum_{e \in p(s,m)} d(e) < \triangle, \tag{1}$$

where $\triangle$ is the delay bound value.

The minimum cost delay constrained multicast tree is a delay constrained Steiner tree T such that

$$\sum_{e \in T} c(e) \tag{2}$$

is minimised.

3 Simulated-annealing-based QOS multicasting algorithm

3.1 The algorithm details

SADLMA belongs to a source-based routing algorithm, because it assumes that sufficient global information is available to the source.

Step 1 Encoding and the initial solution

In SADLMA, a solution is encoded as an array of $m = |M|$ elements, where each element is a path from source s to a destination node $m_i \in M$ in multicast tree T, i.e., $x = (p_1, p_2, \cdots, p_m)$, where $p_i = p(s, m_i)$, $m_i \in M$, $1 \leq i \leq k$.

The initial solution is constructed by randomly select a path from each backup-paths-set[2,8-11].

Step 2 Backup-paths-set

For each destination node $m_i \in M$, we compute least-cost paths from s to m by using the Dijkstra Kth shortest path algorithm to construct a backup-paths-set for generating neighbors. Let p_i be the path set for destination node i:

$$p_i = \{ p_i^1, \cdots, p_i^j, \cdots, p_i^k \}, \tag{3}$$

where p_i^j is the jth path for destination node i.

Step 3 Evaluation function

The evaluation function is used for evaluating state of search. In our algorithm, we take the objective function as an evaluation function

$$f(x) = \text{Cost}(x). \tag{4}$$

Step 4 Neighborhood structure

Let p_i be the path set for destination node i, that is

$$p_i = \{ p_i^1, \cdots, p_i^j, \cdots, p_i^k \}. \tag{5}$$

In the selection process, randomly select $p_i^{j_i} \in p_i$ for the destination node i.

Then obtain the initial solutions

$$T_0 = \{ p_1^{j_1}, \cdots, p_i^{j_i}, \cdots, p_m^{j_m} \}, \quad \{ j_1, \cdots, j_i, \cdots, j_m \}, \quad \text{for short} \tag{6}$$

where $1 \le j_1, \cdots, j_i, \cdots, j_m \le k$, and $j_1, \cdots, j_i, \cdots, j_m$ are positive integer.

Randomly select $j_{s_1}, \cdots, j_{s_i}, \cdots, j_{s_m}$, where $1 \le j_{s_1}, \cdots, j_{s_i}, \cdots, j_{s_m} \le k$.

In the algorithm, we construct neighborhood structure as[8-11]

$$N(T_0) = \{ \{j_{s_1}, \cdots, j_i, \cdots, j_m\}, \cdots, \{j_1, \cdots, j_{s_i}, \cdots, j_m\}, \cdots, \{j_1, \cdots, j_i, \cdots, j_{s_m}\} \}. \tag{7}$$

Step 5 Initial temperature and decrementing the temperature

SA needs to start from a high temperature t_0, so as to allow acceptance of any new neighbor. In SADLMA, set $t_0 = 200$. We use the simplest and most common temperature decrement rule, $t_{i+1} = \lambda \cdot t_i$, where λ is a constant close to 1, but smaller than 1. This exponential cooling scheme (ECS) was first proposed by Kirkpatrick *et al*[12]. In our algorithm, A is set to be 0.95.

Step 6 Acceptance probability

Acceptance probability $f_{ij}(t)$ controls accepting a new solution T_j from neighbors $N(T_i)$ of current solution T_i, i.e.,

$$f_{ij} = \begin{cases} 1, & \text{cost}(T_i) \ge \text{cost}(T_j), \\ \exp(-\Delta_{ij}/t), & \text{cost}(T_i) < \text{cost}(T_j), \end{cases} \tag{8}$$

where t is the current temperature, $\Delta_{ij} = \text{cast}(T_i) - \text{cost}(T_j)$.

Step 7 Termination rule

We use a fixed iteration number as a stopping critertion, and the maximal iteration number is 100. The pseudo code for SADLMA is as follow:

Procedure SADLMA(G=(V,E), $s, M, \Delta, \delta, c, d$)
$T_{\text{best}} = T_{\text{now}} = T_0$; iter = 0; $t = t_0$;
Generate backup-paths-set by using k-SPA;
While iter < MaxIterNum do
Metronum = 0;
While metronum < MaxNum do
GetNeighbors ($N(T_{\text{now}})$, T_{now}, s, M, pathset);
Random select T_j, where $T_j \in N(T_{\text{now}})$;
If $\Delta c = \text{cost}(T_j) - \text{cost}(T_{\text{now}}) \le 0$ then $T_{\text{now}} = T_j$;
If $\text{cost}(T_{\text{now}}) < \text{cost}(T_{\text{best}})$ then
$T_{\text{best}} = T_{\text{now}}$; metronum = 0;
Else if $\exp(-\Delta c/t)$ >random(0,1) then $T_{\text{now}} = T_j$;
Metronum++;
End of while loop
$t = \lambda \cdot t$; iter++;
End of while loop
Return T_{best}

3.2 The complexity analysis

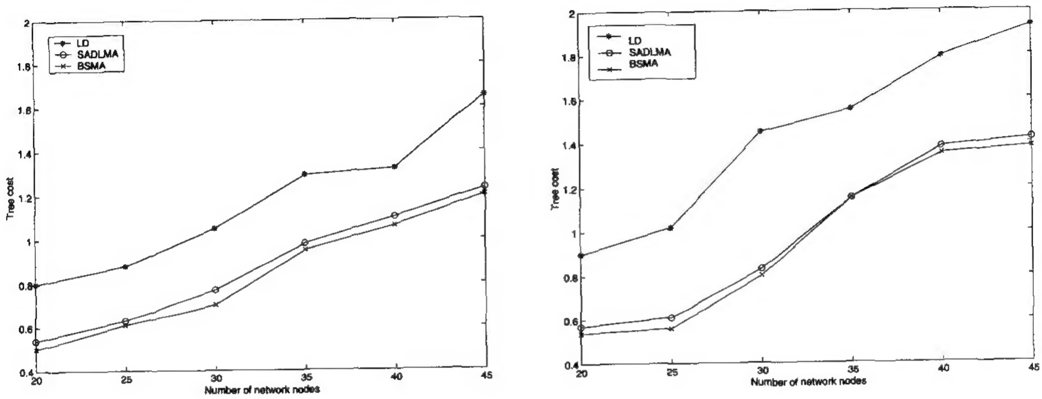
Theorem 1 The time complexity of SADLMA is $O(kmn^3 + M_0Imk)$, where m is the group size, n is the network size, and k is the parameter in k-SPA.

Proof The time complexity of constructing backup-paths-set by using k-SPA is $O(kmn^3)$. In the worst case, generating neighbors costs $O(mk)$, and the complexity of whole simulated annealing is $O(M_0Imk)$, where M_0 and I are maximal number of iterations for constant temperature and termination rule, respectively. The time complexity of SADLMA algorithm is $O(kmn^3 + M_0Imk)$.

4 Simulation results and discussion

The SA algorithm described in this paper has been tested on several randomly generated networks based on the Waxman's algorithm[1].

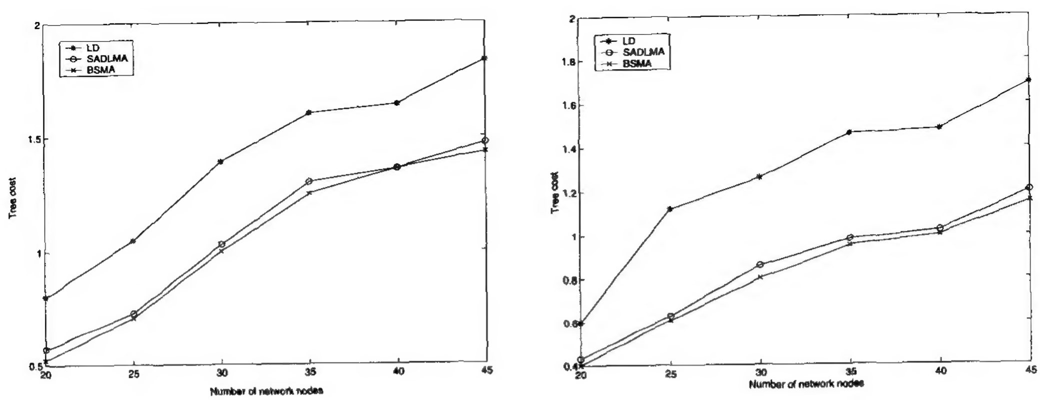
In the first set of the experiments, SADLMA is compared with BSMA and LD for cost performance, where LD is minmum delay Steiner tree without considering the tree cost[2,10] and BSMA is proved to be within 0.07 of the optimal for small networks[1]. Figure 1 shows the tree cost for varying network size with the group size being 4 and 6, respectively; average node degree of network is 3; and $\Delta = 0.3$. The source nodes and destination nodes are varying in each experiment. It can be seen from Figure 1 that our algorithm is of a better cost performance than the LD algorithms, and is close to BSMA, and could construct low-cost trees which satisfy the given delay bound and manage the network resources efficiently.



(a) group size=4 (b) group size=6

Figure 1: Tree cost versus network size for $\Delta = 0.3$; node degree=3

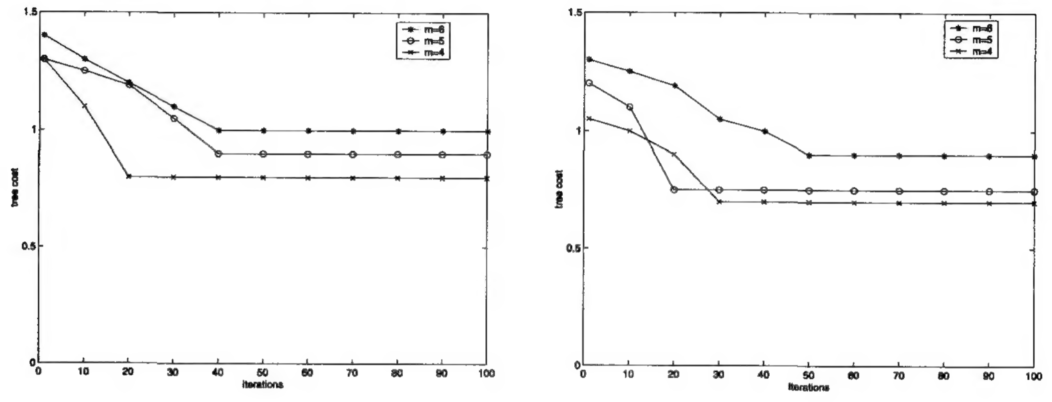
In the second set of the experiments, Figure 2 shows the tree cost for different network size with the group size being 5; average node degree of network being 4 and 5, respectively; and $\triangle = 0.3$. In general, SADLMA has good cost performance and is feasible and effective.



(a) node degree=4 (b) node degree=5

Figure 2: Tree cost versus network size for $\Delta = 0.3$; group size=5

Finally, we consider the iteration time of the algorithm. Figure 3 shows the tree cost for varying the iteration times networks with number of network nodes being 30 and 40, respectively and group size being 4, 5 and 6. As shown in Figure 3, the algorithm converges quickly, and has desirable characteristics of approximation iterative heuristics, which satisfies the real-time requirement of multimedia network.



(a) Number of network nodes=30 (b) Number of network nodes=40

Figure 3: Tree cost versus iteration times for example network

5 Conclusion

A routing algorithm (SADLMA), in which the simulated annealing algorithm is applied to support multimedia group communication, is suggested. The simulation shows that our algorithm is efficient for some actual networks. The algorithm can guarantee the requirement of multimedia group communication for quality of service.

References:

[1] Waxman B M. Routing of multipoint connections[J]. IEEE Journal on Selected Areas in Communication, 1998, 6(9): 1617-1622

[2] Salama H F, Reeves D S, Viniotis Y. Evaluation of multicast routing algorithms for real-time communication on high-speed networks[J]. IEEE J Sel Areas Commun, 1997, 15(3): 332-345

[3] Kompella V P, Pasquale J C, Polyzos G C. Multicasting routing for multimedia communication[J]. IEEE/ACM Trans Network, 1993, 1(3): 286-292

[4] Zhu Q, Parsa M, Garcia-Luna-Aceves J J. A source-based algorithm for delay-constrained mimimum-cost multicasting[J]. Proceedings of IEEE INFOCOM' 95, Boston MA, 1995: 353-360

[5] Aarts E, Korst J. Simulated Annealing and Boltzmann Machines[M]. New York: John Wiley and Sons, 1989

[6] Metropolis N, Rosenbluth A W, Rosenbluth M N, *et al.* Equation of state calculations by fast computing machines[J]. Journal of Chemical Physics, 1953, 21(6): 1087-1092

[7] Kirkpatrick S, Gelatt-Jr C D, Vecchi M P. Optimization by simulated annealing[J]. Science, 1983, 220(4598): 671-680

[8] Sun W S, Liu Z M. Multicast routing based neural networks[J]. Journal of China Institute of Communications, 1998, 19(11): 1-6

[9] Shi J, Zou L, Dong T L. The application of genetic algorithm in multicast routing[J]. Acta Electron Sin, 2000, 28(5): 88-89

[10] Wang H, Fang J, Wang H, *et al.* TSDLMRA: an efficient multicast routing algorithm based on Tabu search[J]. Journal of Network and Computer Applications, 2000, 27(2): 77-90

[11] Kun Z, Heng W, Yu L F. An efficient algorithm based on simulated annealing for multicast routing with delay and delay variation constraints[C]// Proceedings of the 19th International Conference on Advanced Information Networking and Applications

[12] Kirkpatrick S, Gelati-Jr C, Vecchi M. Optimization by simulated annealing[J]. Science, 1983, 220: 671-680
[13] Rouskas G N, Baldine I. Multicast routing with End-to-End delay and delay variation constraints[J]. IEEE JSAC, 1997, 15(3): 346-356
[14] Zhang W X, Xu W H. Cognitive model based on granular computing[J]. Chinese Journal of Engineering Mathematics, 2007, 24(6): 957-971

基于模拟退火法的组播路由算法

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摘 要: 本文提出了一种基于模拟退火算法的延时约束最小代价组播路由算法(SADLMA)。首先，本算法使用Dijkstra第K最短路算法建立了从源节点到每个目的节点的候选集。然后生成了相应的邻居结构。当温度下降时，根据接收概率从邻居结构里把新解选择出来，并且代替旧解。仿真试验表明本算法对实际网络是有效的。

关键词: 组播；模拟退火法；延时约束